

Hazard Profile – Landslide

Summary

- What is a landslide – Landslides are the movement of rock, soil and debris down a hillside or slope. Ground failures that result in landslides occur when gravity overcomes the strength of the soil and rock in a slope, often with the help of contributing factors such as heavy rainfall, erosion of the toe of a slope, ground shaking, or human action.
- The hazard – Landslides take lives, destroy buildings, disrupt infrastructure, interrupt transportation systems, damage utilities, and cause environmental damage. Losses from landslides are difficult to track, but conservative estimates of average losses over the last 30 years are more than \$30 million per year. Nationally, landslides account for more than \$2 billion in losses annually and result in an estimated 25 to 50 deaths a year.
- Previous occurrences – Washington has a long history of landslides. Widespread landslides have historically occurred during large storm events (1983, 1996, 1997, 2007, and 2009) and earthquakes (1949, 1965, and 2001 Nisqually Earthquake). Landslides can also move without large events and without warning, such as the Aldercrest-Banyon landslide in Cowlitz County, the Carlyon Beach/Hunter's Point landslide in Thurston County, and the Nile Landslide in Yakima County. Landslides can also be caused by volcanoes, such as the debris avalanche of the Mt. St. Helens eruption of 1980 and subsequent lahars (volcanic debris flows).
- Susceptibility and probability of future events – Landslides are a natural process and will continue to occur throughout the state. Geologic mapping, landform mapping and landslide susceptibility mapping and modeling are all effective tools in determining areas of instability. Landslide precipitation forecasting is a new tool to forecast landslide initiation during large precipitation events. A collaborative effort is underway to create a statewide landslide forecasting system.
- Jurisdictions at greatest risk – Areas most susceptible to landslides are difficult to determine, since site specific variables can alter susceptibility. Areas typically susceptible to landslides are steep hillsides (20 degrees and greater) and convergent topography. Landforms can also be a factor in landslide susceptibility, such as areas of steep shoreline bluffs, colluvial hollows (bedrock hollows), inner gorges, meander bends, rugged topography (mountainous terrain), and areas with previous deep-seated landslide movement. Features such as alluvial fans can be areas of deposition for debris flows and other landslides.
- Special note – New to the 2010 plan edition is an estimation of potential losses to state facilities due to landslides. Utilizing the OFM 2009 dataset, 42 facilities were determined to be within 500 feet of a landslide, and may, therefore, be at risk to future slide activity. These state owned facilities represent over 123,000 square feet of office space (building cost only). Additionally identified are

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numerous state highways, facilities, and ferry terminals that are partially or completely located in areas susceptible to landslides. See the Loss Estimation portion of the profile for more specific information.

Introduction^{1, 2, 3}

‘Landslide’ is a broad term covering a wide variety of ground-movement and mass-wasting processes, including falls, topples, spreads, and flows (Cruden and Varnes, 1996). Generally, the process involves gravity-driven down slope movement of debris, soil, and (or) rock. This mass continues to move until it reaches stability, sometimes traveling a few feet and sometimes miles from the original location. The duration of these events can be instantaneous to very prolonged, lasting for years to decades. Landslides can injure or kill, destroy structures such as homes, businesses, and public buildings, interrupt infrastructure such as transportation, undermine bridges, derail train cars, impact the environment by disturbing or covering aquatic habitat or directly killing flora and fauna, and can damage or destroy utilities.

Landslides are split into two major categories, shallow and deep-seated landslides. In the Washington Geological Survey’s statewide landslide database (Sarikhani and Davis, 2008), shallow landslides are divided into shallow undifferentiated (including shallow colluvial) landslides, debris flows, debris slides (including debris avalanches and torrents), hyper concentrated flows, and block falls and topples. Deep-seated landslides are divided into lateral spreads, undifferentiated deep-seated landslides, earth flows, translational landslides, rotational landslides, composite landslides, and megalandslides/sturzstroms.

Landslides come in various definitions. In Washington state, two definitions are predominantly used, Cruden and Varnes (1996) and Hungr et al (2001). The Department of Natural Resources, Division of Geology and Earth Resources (aka the Washington Geological Survey) have mostly adopted Hungr’s definitions for landslides. Other agencies, institutions, and private agencies have yet to adopt a standard definition, so it is important to determine what classification system is being used.

Ground failures that result in landslides occur when gravity overcomes the strength of the soil and rock in a slope. While gravity is the primary reason for a landslide, there can be contributing factors, including:

- Saturation, by rain on snow or heavy and/or prolonged rains that can saturate soils and create instability in weakened or weathered bedrock.
- Erosion by rivers, glaciers, or ocean waves that over-steepened slopes or results in removing support from the base of the slopes.
- Ground shaking caused by earthquakes greater than magnitude 4.0 that destabilize slopes and weaken the supporting soils of structures.

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- Volcanic eruptions that produce lahars and instability on the lateral flanks of the volcano.
- Excess weight, from accumulation of rain or snow, from stockpiling of rock or ore, from waste piles, or from manmade structures that exert excessive stress on slopes.
- Human action, such as construction, logging or road building that disturbs soils and slopes and/or increases runoff during prolonged, heavy precipitation events.

Landslides are most likely to occur where certain combinations of geologic formations are present. For example, groundwater percolates through sands and gravels and perches on underlying layers of silt and clay. At this interface, increased groundwater discharging can cause failure of the overlying sand and gravels. In the Puget Lowland, this combination is common and widespread; glacial outwash, often Esperance Sand or gravel, overlies the fine-grained Lawton Clay or Whidbey formation along oversteepened bluffs of the Puget Sound.

Landslides typically occur on slopes and in areas where they have taken place before. Historically, most areas of Washington State have experienced landslides. The Columbia River Gorge, the banks of Lake Roosevelt, the Prosser to Benton City section of Interstate 82, several stretches of the Interstate 5 corridor, the U.S. 101 Highway corridor along the Pacific Coast from Astoria, Oregon to Olympia, in the Cascades, Olympics, and Blue Mountains and Puget Sound coastal bluffs are areas that have been most active in the recent past.

Determining probability of future landslide events in specific locations is difficult because so many factors can contribute to the cause of a landslide or ground failure (see above). A collaboration of scientists led by the Department of Natural Resources, Division of Geology and Earth Resources continue to test a pilot system that warns of increased risk of landslides in Washington State during prolonged, heavy rainfall events. This system will be integrated into the NOAA weather alert system.

Data and Consultation of Landslides

The Washington Geological Survey hosts the Statewide Landslide database, accessible and downloadable (in GIS format) from an interactive ArcIMS site, located at:

<http://wigm.dnr.wa.gov/>. Project specific datasets can be found at:

http://www.dnr.wa.gov/ResearchScience/Topics/GeosciencesData/Pages/gis_data.aspx

If a landslide threatens public safety (for example, threatening or destroying houses, blocking roads, impacting water resources, damming streams/rivers), the Washington Geological Survey is able to provide geologic expertise to public entities on how best to minimize danger and to help determine if residences need to be evacuated. Geologists can also recommend short-term mitigation measures to help reduce damage and potentially movement of the landslide. Contact information can be found on the DNR Geology and Earth Resources webpage located at:

<http://www.dnr.wa.gov/AboutDNR/Divisions/GER/Pages/home.aspx>

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Landslide Provinces⁴

Washington State has six landslide provinces, each with its own characteristics.

Puget Lowland – North Cascade Foothills

This landslide province is the portion of the Puget Lowland overridden by ice during the last continental glaciation. It has abundant rain, or in the foothills, rain and snow. This province has the largest and fastest growing population in the state.

Unconsolidated glacial soil material lies on top of bedrock in the lowland, sculpted and compacted by the last continental ice sheet. During the retreat of the continental glaciers to the north, extensive glacial melt water eroded deep channels in the unconsolidated glacial sediments, resulting in oversteepened, unsupported slopes like those in Hood Canal, the Tacoma Narrows, and Lake Sammamish to name a few. The channels left by the earlier glacial runoff combined with the precipitation runoff in typical northwest maritime climate and Puget Sound wave action has cut hundreds of miles of steep bluffs into the thick, unconsolidated glacial sediments. Many bluffs are in or near population centers; demand for residential development is great on these bluffs because of the economic value of views from the top or access to the beach below. Slope stability maps of the Coastal Zone Atlas (Washington Department of Ecology, 1978-1980) show more than 660 miles of bluffs as unstable.

Four landslide types affect these bluffs:

- *Slump* – This type of landslide occurs when groundwater concentrates on layers of compact silt or clay in the lower bluff area; the existence of a saturated zone can cause the sands and gravels in the upper bluff to subside. Slumps tend to leave a distinctive mid-bluff bench; examples are found in the Alki, Fort Lawton, and Golden Gardens areas of Seattle, Scatchet Head on Whidbey Island, and the Thorndyke Bay area of Jefferson County.
- *Debris flows* – Excessive groundwater combined with focused surface runoff during a heavy precipitation event can turn a landslide into a debris flow which occurs rapidly and typically accelerates with down slope movement. These types of landslides are usually responsible for a majority of the lives lost to landslides around the world annually. Debris flows typically contain trees and large woody debris suspended in a wet, concrete-like soil mixture that can cause loss of, or significant damage to, structures and property. Debris flows that reach a high enough speed can create a localized tsunami wave.
- *Dormant to relict deep-seated landslides in unconsolidated materials* – Dormant and relict deep-seated landslides in the thick glacial sediments of the Puget Sound lowlands are a concern because of their large size, the difficulties the average citizen has in recognizing them, and development pressure, especially in shoreline areas. Reactivation of such landslides generally occur slowly, consisting of a few feet of movement in a particular episode, usually in the late-

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winter or early spring after an unusually wet or series of wet winters. Even a small amount of movement can cause severe damage to structures and utilities.

- *Submarine landslides* – Submarine landslides typically occur on submarine deltas (common in Hood Canal) and along steep submarine bluffs, typically formed by glacial processes. These landslides are apt to go unnoticed unless they trigger noticeable water waves or damage submarine utilities. They have the potential to generate localized tsunamis in Puget Sound.

The Northern Cascade foothills are susceptible to landslides in bedrock. The foothills are subject to moist Pacific storms; the shape and contour of the foothills enhance the amount and intensity of precipitation. Recent studies following the January 7-9th, 2009 storm suggests shallow landslides predominantly occur on the Chuckanut Formation. Deep-seated landslides appear to be more common in the phyllitic rocks, such as the Darrington Phyllite.

- *Debris flows* – These slides commonly enter confined, steeply inclined, flood-swollen stream valleys, becoming more mobile than that of an isolated coastal bluff debris flow, capable of traveling miles from their point of origin. These predominantly deposit on alluvial plains at the base of the hills.
- *Bedrock landslides* – These landslides are in folded and faulted sedimentary and phyllitic rocks that outcrop along the edges of the northern lowland. Nearly all are dormant to relict deep-seated landslides that move by two predominant factors: by removal of support by retreating glacial ice, glacial melt-water erosion oversteepening the valley slopes, or by strong ground shaking during earthquakes.

Southwest Washington

The primary characteristics of this landslide province are the lack of glaciation and localized exposure to glacial melt water. In places, weathering processes have exposed much of the surface in this province for millions of years. Much of the province has deeply dissected terrain, with areas of midslope benches and gentle slopes at the toe of mountain slopes. Recent studies following the December 3, 2007 storm indicate that Crescent and related intrusive rocks are the dominant lithology where shallow (debris flows and debris avalanches) occur. The deep-seated landslides (earthflows and other deep-seated) occur predominantly in the surrounding marine and nearshore sediments.

- *Earthflow* – This is the dominant form of deep-seated landslide in the province. Relict, dormant, and active earth flows are common, not only in the higher steep terrain, but also in the lower rolling hills of the Chehalis-Centralia area. Stream erosion along the toes of the earth flows usually causes reactivation of these landslides. Excavations, such as those for freeway construction, also may reactivate dormant earth flows or initiate new ones.

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- Dormant to relict deep-seated landslides in the Willapa Hills – Dormant to relict deep-seated landslides in the Willapa Hills of southwest Washington are a concern because of their large size and impact on commerce and utility corridors for the rural coastal communities in this part of the State. These deep-seated landslides typically occur along the deeply weathered soil interface with the bedrock. Reactivation of such landslides generally occurs slowly, consisting of a few feet of movement in a particular episode, usually in the late-winter or early spring after an unusually wet winter or during intense precipitation events. Even a small amount of movement can cause severe damage to structures and utilities. It is likely that a number of the large dormant to relict landslides in the Willapa Hills failed during strong ground shaking in this area.
- *Debris flows and Debris Avalanches* – These types of landslides are a widespread problem in the Willapa Hills and foothills to the western Cascade Mountains; they tend to occur where the rocks have steep slopes and smooth surfaces overlain by thin soils. Debris avalanches can cause a rapid movement of material down the hill, blocking rivers and streams and creating temporary debris dams. Both debris avalanches and debris flows can deposit a tremendous amount of debris into the fluvial systems, creating large debris dams behind bridges and natural constrictions. Intense rainstorms, or rain on snow events in the mountains trigger these rapidly occurring landslides.

Cascade Range

This landslide province has a number of different landslide types because of its volcanic and alpine glacial history and climate. There are three sub-provinces in the Cascades – north of Snoqualmie Pass, south of the pass, and the strato-volcanoes, which have distinct slope stability characteristics.

The Cascades north of Snoqualmie Pass are steep and rugged, generally composed of old, strong granitic or metamorphic bedrock. The valley walls typically produce small to very large rock falls. Large deep-seated landslides, from relict to active, dot the landscape. Debris flows and to a lesser extent debris avalanches are common during prolonged, intense rainstorms and during rain on snow events. Some of these landslides have probably been triggered by strong seismic shaking.

South of Snoqualmie Pass, the peaks are primarily composed of younger volcanic sediments and rock; deep-seated landslides, earthflows and block slides in bedrock are common throughout the area. Debris flows and to a lesser extent debris avalanches are common during prolonged, intense rainstorms and during rain on snow events. Large deep-seated landslides in volcanic sediments and bedrock occur in the Columbia River gorge area of the southern Cascades; more than 50 square miles of landslides are in the gorge, but less than 10 percent of the area is active.

The state's five strato-volcanoes – Mount Baker, Glacier Peak, Mount Rainier, Mount St. Helens and Mount Adams – have layers of strong volcanic rock and weak volcanic rock lying parallel to the slopes. These volcanic deposits are prone to failure, with the weaker rock layers on the upper slopes weakened by hydrothermal action. Small rock falls and rock avalanches are common localized hazards on the slopes of the

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volcanoes; but earthquakes have triggered large rock avalanches. These volcanoes can also produce long distance and widespread lahars (also known as volcanic debris flows), which potentially can occur without an eruptive activity.

Okanogan Highlands

This landslide province extends from the slopes of the North Cascades in the west to the foothills of the Selkirk Mountains in the northeast corner of the state. The primary slope stability problem is sediments deposited by repeated damming of the Columbia River by lobes of the continental glacier ice sheet and repeated catastrophic floods from breached ice dams in western Montana.

Debris flows can be a hazard in this area during intense thunderstorms, usually moving through the area during late spring to late summer. The debris flows are generally sparse and due to a sparse population, damage is usually minimal. Deep-seated landslides are most common in the areas surrounding Lake Roosevelt. Deep-seated landslide movement usually occurs in areas where relict to dormant deep-seated landslides exist. Landslide activity was greater when the lake levels were rapidly drawn down for flood control and power generation, but since this type of activity has been largely discontinued, landslides rarely occur from it. Some landslide complexes extend for thousands of feet along the lakeshores, have distinct landslide headscarps in terraces 300 feet or more above reservoir level and extend well below the surface of the water. One hazard in this setting is water waves (inland tsunamis) generated by very large and fast-moving (debris avalanche type) landslides.

Columbia Basin

This province is largely composed of thick sequences of lava flows known as the Columbia River Basalts. These lava flows can be traced from the Oregon, Washington, and Idaho border, where they were erupted from fissures in the ground, to the Pacific Ocean along the northern Oregon and southern Washington coasts via ancestral channels of the Columbia River. Sediments, sometimes thick sections, can be found between these voluminous lava flows in the Columbia Basin. These sediments are generally thicker in the western part of the province.

Between 15,000 and 12,000 years ago, the catastrophic floods originating from Glacial Lake Missoula scoured much of the Columbia Basin from the Spokane Valley to Wallula Gap near Walla Walla before following the Columbia River Gorge to the Pacific Ocean. These catastrophic flood events, as many as 104 separate floods have been documented, scoured the soils and a portion of the bedrock in much of the Columbia Basin before re-depositing it in watersheds along the edges of the main flood way. The catastrophic floods deposited the eroded rock and soil materials in the edge basins, like the Walla Walla River watershed. This left behind a history of the flood events and a soil deposit highly susceptible to erosion capped by wind-blown sands, silts, and clays known as loess. The loess deposits are extensive in the southeastern portion of the Columbia Basin.

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Landslides in this province include slope failures in bedrock along the soil interbeds and in the overlying catastrophic flood sediments and loess deposits. Bedrock slope failures are most common in the form of very large deep-seated translational landslides, deep-seated slumps or earth flows; a triggering mechanism appears to be over-steepening of a slope or removal of the toe of a slope by streams or the catastrophic glacial floods. These landslides usually move along sediment interbeds within the Columbia River Basalts. Major landslide problems occurred during the relocation of transportation routes required by the filling of the reservoir behind the John Day Dam and in the highly erosive and weak loessal soils of southeastern Washington. Rockfall occurs in the oversteepened rock slopes left behind by the erosion of the catastrophic floods along SR 730 and 14.

Irrigation in the Columbia Basin compounds the province's landslide problems. For example, irrigation near Pasco has increased drainage and landslide problems ten-fold since 1957. Reactivations of relict and dormant deep-seated landslide complexes have occurred in the bluffs along the Columbia River upstream of Richland.

Olympic Mountains

The Olympic Mountains consist of a core of sedimentary rock that has been thrust beneath seafloor basalts, causing uplift of the mountains that continues today. Continental glacial deposits overlay much of the bedrock at lower elevations in the Olympic Mountain province. At higher elevations, the larger drainages were occupied by alpine glaciers. The headwaters of the smaller drainages, however, did not accumulate enough snow to form glaciers. The lower valleys that did not have glaciers have thick sections of weathered soil and bedrock comparable to those in the Southwest Washington landslide province. In these areas, rapid debris flows in steep channels and deep-seated slumps or earth flows are prominent. Adjacent valleys that did have glaciers have soils comparable in age, texture, physical properties and behavior to the sediments in the Puget Lowland.

Recently glaciated valleys that head in the core rocks have landslide problems similar to those in the North Cascades. Debris flows are common throughout the Olympics during intense, prolonged precipitation events and during rain on snow events. Rockfall is also prevalent along the glacially oversteepened bedrock slopes of Lake Crescent on SR 101. Slopes composed of older sediments undercut by wave action along the Strait of Juan de Fuca experience extensive deep-seated slumps and earth flows or translational block slides similar to failures discussed in the southern Cascades.

Significant Historic Landslides^{5, 6, 7, 8, 9, 10, 11, 12, 13, 14}

Landslides occur throughout Washington State, but only a portion of landslides have been mapped or recorded. The list of landslides below represents a portion of landslides occurring in Washington State. Most landslides, especially in the recent section below, reflect mostly urban areas, in which landslides are more readily documented. Landslides have occurred outside of the urban areas, but are largely undocumented.

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>20,000BC (est.) – The Malaga (Stemilt) Landslide is the largest landslide complex in Washington State and one of the largest landslides in the world. Movement was probably caused by weak sedimentary rock interbedded with Columbia River Basalt. The landslide size is approximately 46 sq. miles in area, twice the size of the debris avalanche from the 1980 eruption of Mt. St. Helens.

400-600BC (est.) – The Church Mountain landslide occurred along the North Fork of the Nooksack River. It is considered a sturzstrom, a fast moving rock avalanche of very large size. It was probably triggered by an earthquake.

900AD (est.) – A Seattle fault earthquake occurred around this time, spawning landslides throughout Washington State. Landslides from this event blocked streams and rivers, some becoming permanent. Buried wood in these lakes helped date landslides to this event. Most notably is the Alderwood Landslide near Lynch Cove, which could have triggered a tsunami in Hood Canal. Landslides from Mercer Island into Lake Washington and a landslide at Greenwood Point into Lake Sammamish Lake Sammamish also date to this time.

1700AD – A Cascadia subduction zone earthquake was the last major subduction earthquake off of Washington's coastline. Numerous landslides were triggered from this earthquake. Slide Lake and Day Lake in Skagit County have been dated through a submerged forest to probably correlate to this event.

1550 – 1700 (est.) – The Bonneville Landslide, a landslide inside the Cascade Landslide Complex, is in the Columbia River Gorge 30 miles east of Vancouver. Dating from a tree found in the debris suggests this landslide could have been seismically triggered from the 1700 Cascadia Earthquake. The landslide from Table Mountain shoved the river a mile off course and created a lake that may have stretched east for 100 miles. It is the youngest and largest of three landslides that make up the 14-square mile Cascade Landslide Complex north of the Columbia River near Cascade Locks and Stevenson. Explorers Lewis and Clark documented the landslide and its effects in 1803.

Early 1800s – Historical accounts among the Snohomish people describe a large landslide at Camano Head that sent a tsunami south toward Hat Island. According to tribal accounts, the landslide sounded like thunder, buried a small village and created a large volume of dust. The accounts make no mention of ground shaking, suggesting that the slide was not associated with a large earthquake. Camano Head is at the south end of Camano Island in Puget Sound.

1872 – A landslide, triggered by a 6.8 (est.) magnitude earthquake, reportedly blocked the flow of the Columbia River north of Wenatchee for several days (although some scientists dispute this). The landslide was a translational deep-seated landslide and one of many landslides to move during the earthquake. Many more landslides are noted around Lake Chelan from this earthquake.

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1894 – A submarine landslide in the delta of the Puyallup River in Commencement Bay, Tacoma, caused a tsunami. These events carried away a railroad track and roadway, resulting in two deaths.

1896, 1897, and 1902 – Rain on snow events in the Cascades produced numerous landslides throughout the region. Mining operations and railroads reported landslides in transportation routes or in areas of operation.

1944 to 1953 – Massive landslides generated a number of inland tsunamis in Lake Roosevelt in Eastern Washington:

- *April 8, 1944* - A four to five million cubic yard landslide from Reed Terrace generated a 30-foot wave, 5,000 feet away on the opposite shore of the lake about 98 miles above Grand Coulee Dam.
- *July 27, 1949* - A two to three million cubic yard landslide near the mouth of Hawk Creek created a 65-foot wave that crossed the lake about 35 miles above Grand Coulee Dam; people 20 miles away observed the wave.
- *February 23, 1951* – A 100,000 to 200,000 cubic yard landslide just north of Kettle Falls created a wave that picked up logs at the Harter Lumber Company Mill and flung them through the mill 10 feet above lake level.
- *April 10 – 13, 1952* – A 15 million cubic yard landslide three miles below the Kettle Falls Bridge created a 65-foot wave that struck the opposite shore of the lake. People observed some waves six miles up the lake.
- *October 13, 1952* – A landslide 98 miles upstream of Grand Coulee Dam created a wave that broke tugboats and barges loose from their moorings at the Lafferty Transportation Company six miles away. It also swept logs and other debris over a large area above lake level.
- *February 1953* – A series of landslides about 100 miles upstream from Grand Coulee Dam generated a number of waves that crossed the lake and hit the opposite shore 16 feet above lake level. On average, observed waves crossed the 5,000-foot wide lake in about 90 seconds.
- *April – August 1953* – Landslides originating in Reed Terrace caused waves in the lake at least 11 different times. The largest wave to hit the opposite shore was 65 feet high and observed six miles away. Velocity of one of the series of waves was about 45 miles per hour.
- *January 16, 2009* - A section of hillside approximately 17 acres in size across from Breezy Bay in Lake Roosevelt broke free. The landslide had fallen into the water, created a wave that was about 30 feet high when it hit the shore about a thousand yards across the lake. The wave damaged or destroyed several private docks located at Breezy Bay, Moccasin Bay, Sunset Point and Arrowhead Point. Several vessels moored in the area were also swamped and left beached on

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land. The water reached one residence before receding and came just to the foundations of several others.

- August 25, 2009 - A large landslide occurred near the Blue Creek drainage on the Spokane Indian Reservation side of the Spokane Arm of the lake. Like the one that occurred on January 16th of this year, responding park staff found that a large section of hillside had broken free, creating a wave that was approximately 12 feet high by the time it hit Porcupine Campground on the southern shore less than a thousand yards across the lake.

1949 – On April 13, 1949, a magnitude 7.1 earthquake initiated in the Puget Sound Region. Landslides generated by the earthquake were reported predominantly in the Cascade Range, Puget Lowlands, and the western Columbia River Valley. In urban areas, landslides in the form of slumps, slides, and flows, occurred in areas of fill, such as roads and roadways, and areas unstable by undercutting, such as along coastal bluffs and along banks of rivers and lakes. Landslides, such as rock falls, rock slides, and rock avalanches were concentrated in the Cascade Range and Columbia River Valley. A landslide at Salmon Beach occurred three days after the April 16 magnitude 7.1 earthquake generated a tsunami in the Narrows of Puget Sound near Tacoma. According to local newspaper reports, an 11 million cubic yard landslide occurred when a 400-foot high cliff gave away and slid into Puget Sound. The slide narrowly missed a row of waterfront homes, but the tsunami damaged them.

1965 – Ground shaking produced by the April 29 Seattle-Tacoma earthquake generated at least 21 landslides within about 60 miles of the epicenter. A number of landslides were recorded, including:

- Slumping along a steep slope adjacent to 36th Avenue SW near Admiral Way in West Seattle, and a landslide that uncovered an underground stream that overflowed a creek and broke a water main at Carkeek Park in South Seattle.
- Landslides on Lake Holm Road east of Auburn.
- Part of Crescent Lake Road near Gig Harbor sinking and being covered by water.
- Cracking of canyon walls of the Nisqually River gorge and landslides into the river and onto roads near LaGrande.
- Landslides on both Jones Road and Devils Elbow Road near Maple Valley.
- A large landslide on the southwest slope of Mount Si near North Bend.
- Landslides that heavily damaged Deschutes Parkway around Capitol Lake in Olympia and broke a sewer line and railroad tracks near Tumwater.
- A landslide undermined a road, and a portion of beach heaved at Suquamish.

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1965 – A landslide-triggered tsunami overran Puget Island in the Columbia River near Cathlamet. The landslide originated from Bradwood Point on the Oregon side of the river. The wave killed one person.

1980 – A 5.1 magnitude earthquake near Mount St. Helens on May 18 triggered the largest modern debris avalanche – an estimated 3.7 billion cubic yards, or 0.67 cubic miles – in recorded history. The earthquake dislodged the summit and bulging north face of the volcano, depressurizing the volcano's magma system, triggering powerful explosions and a massive eruption. Lahars (volcanic debris flows) flowed down the Toutle River, converging with the Cowlitz River and ending in the Columbia River. Lahars also were reported in Swift Creek, Pine Creek, and Muddy River drainages.

Recent Disasters with Landslides

February 1996 – Storms and Landslides^{15, 16}

Near-record snowfall in January followed by warm, heavy rain, mild temperatures and snowmelt in February caused a classic rain-on-snow event, triggering massive flooding and landslides throughout the state. The storm caused three deaths, and 10 people were injured. Landslides damaged or destroyed nearly 8,000 homes, and closed traffic along major highways for several days. Damage from all causes throughout the Pacific Northwest was at least \$800 million.

Stafford Act disaster assistance provided – \$113 million. Small Business Administration disaster loans approved - \$61.2 million.

The landslide that created the most significant impact blocked Interstate 5 and the state's main north-south railroad tracks three miles north of Woodland, Cowlitz County. The initial slide on February 8 blocked northbound lanes of I-5; a second, larger slide covered all lanes of the freeway as well as the railroad tracks to the west. It took crews until February 19 to fully reopen the interstate.

The highest concentration of landslides occurred at the northwest edge of the Blue Mountains near Walla Walla. The main areas affected were the Mill Creek, Blue Creek, Touchet, Tucannon, and Walla Walla drainages. Debris flows were most numerous on open, grassy hillsides. In the Mill Creek area, debris flows destroyed seven vehicles and five homes. Similar occurrences of flooding and landslides took place in 1931 and 1964.

Seattle recorded more than 40 landslides during the winter, about two-thirds related to this storm. Most involved failure from steep coastal cliffs. Landslides damaged or threatened homes on Perkins Lane, Brygger Drive, Laurelcres Drive, and California Way. Elsewhere in King County, a landslide blocked State Route 410 east of Enumclaw.

In Pierce County, landslides destroyed two homes and damaged another along with utility lines at Salmon Beach, Tacoma. A landslide hit two homes and covered a portion

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of Marine View Drive, and closed southbound lanes of Schuster Parkway. North of Gig Harbor, two debris flows destroyed one house and damaged three others. A landslide pushed two locomotives and two rail cars into Puget Sound, resulting in a 3,000-gallon fuel spill. Numerous debris flows damaged State Route 165 and undermined a bridge abutment at the Carbon River near Carbonado.

In Thurston County, numerous landslides in the Olympia area severed two sewer lines resulting in a 6 million gallon sewage discharge into Capitol Lake. Numerous debris flows occurred on the bluffs below the Capitol Campus that covered railroad tracks and an adjacent road, and just missed a steam plant that produced heat for the campus.

Lewis County had the largest landslide, with an estimated 1.5 million cubic yards of debris; it destroyed a house five miles east of Glenoma. Landslides blocked State Route 504 in two places by landslides in Kid Valley, and a landslide closed State Route 7 near Mineral Lake for two days.

In Clark County, numerous landslides blocked rail lines near Vancouver Lake, and a train was buried by debris. In Hazel Dell, a house was broken in two by a debris flow. Landslides closed or partially covered State Route 14 in 15 different areas for 80 miles between Washougal and Wishram. Just south of Woodland, a landslide predating the February 1996 storm but accelerated by it covered the Northwest Pacific Highway.

In Skamania County near Stevenson, a large reactivated landslide complex removed three homes from their foundations, and a debris flow covered State Route 141 near White Salmon.

Other landslide damage included:

- Numerous debris flows and landslides that damaged local and county roads and closed State Route 4 west of Skamokawa, Wahkiakum County.
- Numerous debris flows partially covered State Route 503 Lewis River Road.

December 1996 – January 1997 Holiday Storms and Landslides^{17, 18, 19}

Snowmelt and rainfall in late December 1996 and January 1997 triggered hundreds of landslides and debris flows in the steep bluffs and ravines that border Puget Sound, Lake Washington, and the larger river valleys between late December 1996 and mid March 1997. Landslides caused the deaths of at least four people, millions of dollars of damage to public and private property, lost revenues, traffic diversions, and other losses.

December precipitation was 191 percent of normal. More than 130 landslides occurred between Seattle and Everett, primarily along shorelines. Although shallow slides and debris flows were the most common slope failures, many deep-seated slides also occurred. Many bluffs and steep hillsides were sites of recurring failures.

Hazard Profile – Landslide

Federal Disaster #1159. Stafford Act disaster assistance provided – \$83 million. Small Business Administration loans approved – \$31.7 million.

Most landslides that resulted from these storms occurred mainly in and north of Seattle – along the bluffs of Puget Sound, Lake Washington, Lake Union, Portage Bay, West Seattle, Magnolia Bluff, and along the I-5 corridor. Many smaller landslides were scattered west and south of Seattle in Kitsap and Pierce counties.

A landslide on January 15 derailed five cars of a freight train on the shore of Puget Sound midway between Seattle and Everett. Freight traffic was running again although at reduced speed by January 24, while Amtrak was not able to use the track for several weeks while safety issues were resolved.

A debris flow slide on January 19 killed a family of four at Rolling Bay Walk on Bainbridge Island. A number of debris flows from the storms were visible along the undeveloped bluff not far from the house; more debris flows occurred at Rolling Bay Walk on March 18 and 19, damaging two homes and pushing a third onto the beach.

About 20 to 30 landslides occurred in Pierce County, including along Schuster Parkway, Salmon Beach, and the Narrows. One landslide cut phone service to homes on Salmon Beach.

Saturation of soils in Whatcom and Clark Counties caused landslides that resulted in the rupture of two interstate natural gas lines, causing explosions; no injuries reported. Residents near the line in Whatcom County evacuated until it was shut down. In Clark County, the incident resulted in a fire that caused significant damage to a nearby commercial structure under construction.

October 1998 – Aldercrest Landslide Disaster^{20, 21}

Federal Disaster #1255. Stafford Act disaster assistance provided – \$12.1 million. Small Business Administration disaster loans approved - \$38.7 million.

The Aldercrest Landslide Disaster is the second-worst landslide disaster in United States history. Of the 137 homes in the east Kelso, Cowlitz County, neighborhood, the landslide destroyed or badly damaged 126 homes; a demolition contractor eventually removed the damaged structures.

This ancient landslide began moving in March 1998 after soils were saturated by three straight years of above average rainfall.

Eleven homeowners remained on a bluff above the slide; geologists say their houses eventually will succumb to the slide.

January-February 1999

Four large landslides occurred within portions of pre-historic landslide complexes closing WSDOT highway facilities for several months. There were two landslides along

Hazard Profile – Landslide

the Hood Canal portion of SR 101 between Hoodspoint and Jorsted Creek at MP 322 and 326; another one on SR 3 near the town of Allyn in the vicinity of MP 22.5; and a large landslide on SR 166 at Ross Point between MP 1.29 and 1.77.

During this event, landslides also affected homes and private and county roads at Carlyon Beach/Hunter Point, Sunrise Beach, and Sunset Beach in Thurston County. Forty-four homes were declared unsafe for human inhabitation. At Sunrise Beach, Thurston County government and property owners were successful with engineering and construction efforts to stop the slide; property owners paid for these actions. Landslides continue at Carlyon Beach.

Nisqually Earthquake – February 28, 2001²²

Federal Disaster #1361. Stafford Act disaster assistance provided to date – est. \$155.9 million. Small Business Administration disaster loans approved - \$84.3 million. Federal Highway Administration emergency relief provided to date - \$93.8 million.

The earthquake, magnitude 6.8, struck the Puget Sound area at 10:54 a.m. It produced a number of significant, but widely scattered landslides that caused damage resulting in direct monetary losses of \$34.3 million; indirect costs such as loss of productivity, revenues and tax receipts, reduced real estate values, injuries, and environmental impacts are not included.

Among the significant landslides caused by the Nisqually earthquake are the following:

Salmon Beach, Tacoma – A 1,300 cubic yard landslide demolished two homes at the base of the bluff. The landslide damaged sewer, water and electrical lines. A much larger slide – estimated at 13,000 to 26,000 cubic yards – moved at the top of the bluff threatening another eight homes. This waterfront community on the Tacoma Narrows also experienced landslide damage during the 1949 earthquake. Estimated damage caused by the smaller landslide is \$1.5 million.

Cedar River, Renton – Two landslides occurred along the banks of the Cedar River. One, estimated at 50,000 cubic yards, demolished 200 yards of a flood control facility and blocked the river until a ditch was dug through the debris. A second carried 10,000 cubic yards of material into a house, breaking it in two and filling half the structure with debris. The landslide narrowly missed burying the home's occupant. Estimated damage caused by these slides is \$1.7 million.

Capitol Lake/Deschutes Parkway, Olympia – The parkway experienced significant damage from lateral spreading, liquefaction and ground failure during the earthquake, as well as from a landslide six weeks later. Several lateral spread landslides occurred around the margins of Capitol Lake; they damaged water and sewer lines as well as Marathon Park. Estimated damage caused by these landslides is \$22.2 million.

Maplewild Avenue, Burien – Five homes perched along a steep slope sustained structural damage when underlying fill formed a landslide. One house was demolished

Hazard Profile – Landslide

and two others badly damaged. The street also was damaged between 29th Place SW and 33rd Avenue SW. Estimated damage caused by the landslide is \$7.6 million.

Tolmie State Park, near Olympia – Lateral spreading damaged sewer and water lines, bridges, trails and a kitchen shelter, resulting in temporary closure of the day-use marine park. Estimated damage caused by the landslides is \$348,000.

Sunset Lake-Trosper Memorial Trailer Park, near Tumwater – A lateral spread and other failures damaged the perimeter road, a two-inch natural gas line serving the trailer park and a number of mobile homes; damage estimates not available.

U.S. Highway 101, Thurston County – The northbound lanes of the highway near its junction with State Route 8 west of Olympia slid away during the earthquake. A slump/debris flow of about 20,000 cubic yards removed one lane of the highway and flowed down a slope between two homes before ending up on a surface street below. Estimate damage caused by the slide \$919,570.

Other areas where landslide caused damage includes King County International Airport/Boeing Field, Harbor Island in Seattle, Chambers Creek near Steilacoom, State Route 302 near Allyn, State Route 202 near Snoqualmie, Victor Fill near Olalla, and Interstate 405 at 44th Street in Renton.

October 2003 – Floods and Storms

Federal Disaster #1499. Stafford Act disaster assistance provided to date – \$ 5.8 million. Small Business Administration disaster loans approved – \$ 2.1 million.

Heavy rainfall caused severe flooding and landslides in 15 counties. Landslides or ground failures caused temporary closures on nine state highways. Among the most significant events were a series of mud and rockslides that closed State Route 20 between Skagit and Okanogan Counties, and a landslide on State Route 112 in Clallam County that isolated the Makah Indian Reservation near the Sail River. Other landslide-related transportation problems included debris over the roadway or lodged beneath bridges on U.S. Highway 101 in Jefferson and Mason Counties, U.S. Highway 2 in Snohomish County, and State Route 410 in Pierce County.

The most significant was a series of rockslides that closed State Route 20, the North Cascades Highway. The largest, estimated at two to three million cubic yards, demolished the highway and isolated the town of Diablo. People and supplies were shuttled in and out of the town via helicopter for a month during the winter. The highway reopened April 8, 2004 for the season (the highway closes during the winter due to the threat of snow avalanche). Electronic monitoring devices connected to warning signs were installed to detect rock movement and to warn drivers if a rockfall occurs or is imminent.

Hazard Profile – Landslide

Recent Landslides

In 2004: ^{23, 24, 25}

- January – Rapid snowmelt and rainfall on January 8 triggered a mudslide in North Seattle blocked the railroad tracks around Carkeek Park, halting the Sounder commuter train service for 48 hours. A debris avalanche/debris flow closed the I-90 onramp in Issaquah on January 31, at the Sunset Interchange. The landslide was reported to be about 25,000 cubic yards.
- February – On February 4 two rockslides blocked Interstate 5 south of Bellingham, causing a multi-day closure of one lane of southbound traffic.
- March – On March 12, a slide moved into the Cedar River near Renton. The landslide reportedly caused a wave of water that hit a house. The landslide partially dammed the Cedar River, but it eroded down through the debris and returned to a normal flow.
- August – An intense thunderstorm on August 16-17 triggered four landslides near Rainy Pass, stranding 40 motorists and 25 firefighters. The landslides occurred on the North Cascades Highway at mileposts 149, 150, 153, and 156. Heavy rains also caused a wash out (by a debris flow or hyperconcentrated flow) on a USFS road leading to Harts Pass.
- November – A debris flow along Sygitowicz Creek blocked Highway 9, isolating about 15 families in the town of Van Zandt.
- December – A debris avalanche fell into the Sultan River on Dec. 11, as a storm rolled through the area. The landslide temporarily blocked the Sultan River, but eventually was eroded down. The landslide was caught on tape by kayakers on the river.

In 2005: ²⁶

- January – A small landslide occurred on Chuckanut Drive around January 10. A rain on snow event on January 17 caused minor flooding, but only a few reported landslides. In Seattle a small landslide blocked West Galer Street and a landslide on Chuckanut Drive near the Skagit Whatcom Counties boundary.
- May – A small landslide on Mercer Island on May 22 isolated 11 homes and blocked Forest Avenue SE. The landslide was probably triggered by leaking water and recent rains. A large storm system in Eastern Washington brought heavy rainfall in Adams, Lincoln, and Chelan Counties. Flash flooding and debris flows were reported in this event, the biggest in Chelan County on the South Lakeshore Drive.
- September – A large rockslide in the early hours of Sept 11 collapsed onto a car, killing the three women inside. The landslide closed two westbound lanes and

Hazard Profile – Landslide

produced up to 30 dump truck loads (~300 cu.ft.) of rock to clear. The landslide occurred several miles west of Hyak. A smaller rockslide also occurred on Sept 12 a few miles west of Snoqualmie Pass, causing no fatalities and closed two westbound lanes.

- November – A large rockslide just east of Snoqualmie Pass closed I-90 on Nov. 6, but reopened two lanes late Nov. 7. The landslide restricted and slowed traffic through the area for about two weeks near the Thanksgiving holiday weekend. Motorists were advised to take alternate routes through the Cascade Mountains, and the State Patrol used traffic control measures to limit and slow traffic through the slide area. The landslide was stabilized by removal of loose material and by the installation of a mesh fence to prevent additional rock fall from entering the roadway. Workers removed about 100 dump truck loads (~1,000 cu. ft.) of debris from the site.
- December – A rockslide on Dec. 10 occurred near the east end of Crescent Lake on the Olympic Peninsula, closing one lane of US 101. A landslide occurred on Dec. 25, closing Juanita Drive in the northeast area of Kirkland. The landslide occurred between Northeast 116th Place and 86th Avenue Northeast. The landslide was probably triggered by heavy rains in the area, which also produced localized flooding. Another landslide occurred south of Tacoma also on Dec 25, covering railroad tracks with three feet of mud by 30 feet wide.

In 2006: ²⁷

- January – Prolonged rainfall from Dec. 2005 into Jan. 2006 caused numerous landslides throughout the state. Records of landslides are best documented in King County, but other counties also had numerous landslides move. Slides, slumps or settlement closed lanes of Interstate 5, U.S. 101, SR 4, SR 9, SR 14, SR 107, SR 105, SR 112, SR 116, SR 166, SR 302 and SR 530 for various periods.

Heavy rains on Jan. 5 and 6 triggered four landslides on the coastal bluffs between Seattle and Everett. The rainfall totaled 1.49 inches in a 24 hour period. Several landslides occurred on the coastal bluffs in the Seattle Area, one between Golden Gardens and Carkeek Parks which was about 30 feet wide and almost 3 feet deep, one between Mulkiteo and Edmonds, another about a mile north of Golden Gardens Park, the last was two miles south of Mulkiteo. The landslides closed passenger train service for a federally mandated 48 hour, the first time since December 2003. On the eastern slopes of the Cascades, a debris flow moved across Highway 2, 8 miles east of Leavenworth. The intense rainfall continued into Jan. 7, causing concern for additional landslide movement. A landslide moved mud and debris on Highway 166 near Port Orchard, closing the highway for at least two days and forcing vehicles to make a 5 mile detour. The U.S. Geological Survey issued an advisory that if 1 inch of rain fell within the Puget Sound Region within the next few days; a threshold would be reached and would likely trigger more landslides in King, Pierce and Snohomish Counties.

Hazard Profile – Landslide

On Jan. 10, rainfall continued to plague the area and landslides once again moved on the coastal bluffs, closing passenger train service. The landslides occurred three miles south of Tacoma, another in Shoreline and the last between Edmonds and Everett. A mudslide also occurred in the University District, bulging a retaining wall at Phi Kappa Psi fraternity house annex in the 4700 block of 22nd Avenue Northeast. Two other landslides also occurred on Mercer Island, one along a section of Pohl Road, about a fourth of a mile from the Vashon Highway, the other on Burma Road. Along I-5 a landslide closed a northbound lane near the Nisqually basin. In Everett, a landslide closed the Siever Ducey Road, nearly swallowing a car driving down the road.

Jan. 10 marks the 23rd consecutive day of rain in Seattle. In Skagit County, a landslide blocked Highway 20 one half mile east of Concrete. On Jan. 11, flooding triggered either a landslide or erosion on the Issaquah Hobart Road near Tiger Mountain, closing the road between 255th Ave SE and SE 164th Street. A deep-seated landslide buckled Highway 107 near Raymond prior to Jan. 12 (exact date unknown), completely closing it.

Jan. 14 brought on the 27th straight day of rain for the Seattle area, producing 13 inches of rain since Dec. 19, 2005. Governor Christine Gregoire declared a state of emergency on Jan. 13 following unprecedented rainfall and \$7.3 million in damage to infrastructure (primarily transportation) in Clallam, Grays Harbor, Jefferson, King, Kitsap, Lewis, Mason, Pacific, Pierce, Skagit, Spokane and Thurston counties. Landslides have been occurring throughout western Washington, although many go unrecorded. Jan. 14 brought another landslide, this time at a residence east of Renton at 156th Place SE. The debris flow partially buried cars, filled a retention pond and covered driveways. King County red tagged the house impacted by the landslide and a mobile home across the road. A landslide also occurred on Dorre Don Way SW, near Maple Valley and near Cedar River. This landslide was one of three that was triggered at that location between Jan. 14 to Jan. 15. Jan. 16 was the start of a reprieve from the rain, but the saturated slopes continued to move. A landslide occurred south of Tacoma on the railroad tracks, once again closing passenger service for a mandated 48 hours. The landslide was reported to be about 3 feet deep by 40 feet wide.

Jan 25 brought a major landslide along the North Fork of the Stillaguamish River. A massive landslide in Steelhead Haven, between the town of Oso and Hazel, diverted the river into a neighborhood, and threatening about a dozen homes. The landslide also deposited sediment into the river, creating environmental damage downstream and reducing the fish population.

The end of January brought another storm, triggering landslides. On Jan. 30, a landslide was reported on the Lake Dorothy Road near North Bend. A landslide in the Shoreline area once again moved onto the railroad tracks, shutting down passenger train service for a mandated 48 hours. Soon after, another 7 landslides covered tracks from Everett to Nisqually Valley. In Mason County, a

Hazard Profile – Landslide

landslide closed Highway 302, east of Highway 3 (near Case Inlet). A landslide also closed Highway 166 near Port Orchard. In Thurston County, a landslide blocked one lane of northbound I-5 north in the Nisqually Reach and another near Bucoda on Highway 507.

- February – On Feb. 3, Governor Christine Gregoire signed an Emergency Proclamation requesting federal funds for all 39 counties. Feb. 5, a landslide 23 miles south of Tacoma once again slid over railroad tracks, closing service for passenger trains for 48 hours. Other landslides were also reported on the track. A deep-seated landslide was noticed around Feb. 6 on Highway 530, where a 250 foot section of road moved 6 inches. The route is the main access to Darrington and threatens to isolate the town.
- March – A landslide on Mar. 1 moved over the 7800-7900 block of West Mercer Way on Mercer Island, isolating five homes.
- April – A large landslide on April 18 covered the railroad tracks in the Everett area. The landslide was 70 feet long, creating a debris field 100 feet long and 4-5 feet deep. The landslide occurred without any significant rainfall. The landslide stopped passenger train service for the mandated 48 hours.
- May – At about 9 p.m. on May 13, a large section of bluff on Basin Hill moved and covered about a quarter of a mile of road 170 between Klamath and Sheffield roads, to a depth of up to 40 feet in places. The landslide destroyed a grain bin, damaged power lines and an irrigation circle, and narrowly missed a mobile home. The landslide also blocked an irrigation canal, cutting off water to about 20 landowners and as much as 2,000 acres of farmland. A similar landslide occurred at this spot about 25 years ago.

Hazard Profile – Landslide



Figure 1. At about 9 p.m. on Saturday, May 13, a large section of bluff sloughed off and covered about a quarter-mile of Road 170 between Klamath and Sheffield roads to a depth of about 40 feet. The slide destroyed a grain bin, damaged power lines and an irrigation circle, and narrowly missed a mobile home. It also choked an irrigation canal, cutting off water to about 20 landowners. A similar landslide happened in almost the same spot about 25 years ago. Photo courtesy of the South Columbia Basin Irrigation District.

On May 17, the President declares major disaster for Washington State, opening up federal funds for emergency work and repairs for the period of Jan. 27 to Feb. 4.

A debris flow on May 18 came down a small feeder creek about 4,000 feet off Icicle Ridge, flowing into the Wenatchee River. The debris diverted the river onto Highway 2 for a short time.

- June – On June 12, an intense thunderstorm rained at rates of 1 to 2 inches in a half hour. Reports came in of hillsides washing away and numerous flash flooding (possibly debris flows or hyperconcentrated flows) around the Entiat River Basin, Eagle Creek and the Ollala Canyon. The Big Creek Campground on Lake Chelan was destroyed by a flash flood (hyperconcentrated flow?). In the Entiat River Valley, a landslide filled a house with mud, trapping two women inside, neck-deep in mud for an hour before being rescued. The landslide knocked the house off of its foundation. This was one of at least a dozen landslides in the area. Another severe thunderstorm on June 13th struck Spokane County, triggering a debris flow or hyperconcentrated flow and washed out T.J. Meenach Road.
- July – An intense thunderstorm struck parts of Chelan and Okanogan County on July 5, triggering flash flooding and debris flows. The most prominent was on

Hazard Profile – Landslide

Lake Chelan near Slide Peak, where a debris flow covered the South Shore road with up to 3 to 10 feet of rocks the size of small cars, mud and debris. A debris flow also occurred on a road near the town of Methow, blocking it. On July 6, a severe thunder storm across Okanogan County dropped 1.15 to 1.45 inches of rain in one hour. A debris flow covered the junction of Loomis-Oroville Road and Horse Springs Coulee Road.

- November- A Pineapple Express packed with wind and heavy rain moved into Western Washington on November 6, bringing flooding and landslides. Governor Christine Gregoire declared a state of emergency for 18 counties. A landslide occurred near Lake Crescent, blocking one lane. In Pend Oreille County, a large rockfall closed Highway 395, hitting a truck and a car. The occupants escaped unharmed. King County had a small amount of landslides across the area; one near Raging River destroyed the access to Upper Preston and temporarily isolating 200 homes. State Route 508, on the east side of Bear Canyon, failed and the road was closed for several months while repairs were made to the highway. The upper Cowlitz River valley was particularly hard-hit with numerous slides and debris flows that destroyed houses and seriously impacted state and local transportation infrastructure.
- December – A strong storm known as the Hanukkah Eve Wind Storm of 2006, brought hurricane force wind gusts and heavy rains to Western Washington between Dec 14 and Dec 15. The storm brought with it a small amount of landslides reported around Western Washington, but was overshadowed by the enormous wind damage and the resulting loss of 1.8 million residences and businesses without power. Seattle reported five (5) landslides across the city, one at East Highland Drive near Lakeview Boulevard East, at 1038 Elliott Ave, and another at Lakeview Boulevard East, just off I-5 in the Capital Hill neighborhood. Another landslide was reported along Juanita Drive NE.

The end of December brought more landslides to the Puget Sound coastal bluffs. A landslide just north of Carkeek Park in Seattle covered railroad tracks 20 feet wide and about a foot deep on Dec. 26. The landslide stopped passenger rail service for a mandated 48 hours.

In 2007:

- February – In Skamania County, in the town of Stevenson, a landslide was starting to show cracks in the hillside along Rock Creek in early February. The landslide accelerated in movement and expanded in size, eventually displacing or destroying two houses. The landslide probably formed by prolonged rains in the area in November of 2006. Downstream of the landslide, in the City of Stevenson, debris has clogged Rock Creek, threatening to destroy a bridge (with utilities) and threatening the cities sewage treatment plant. As of Oct. 2009, the landslide has slowed in movement and has not expanded any further.
- During a prolonged cold spell east of the Cascade Mountain Range, a large rockfall event closed one lane of State Route 20 in the vicinity of MP 301.8 for two days, just west of Republic.

Hazard Profile – Landslide



Figure 2. Landslide at Rock Creek north of Skamania, taken on November 16, 2007.

- March – The Suiattle River Road near Darrington was closed by a landslide in early March. The landslide did not isolate any permanent residences, but closed off access for recreational cabins and hiking. A landslide on March 26 closed State Route 504 (Spirit Lake Memorial Highway), east of Kid Valley. The landslide blocked access to Coldwater Visitor Center, Hoffstadt Bluffs Visitor Center and Johnston Ridge Visitor Center.
- April – A sinkhole formed on Highway 2 near Index in Snohomish County. The hole was about 5 feet in diameter and 4 feet deep. The sinkhole was the result of a landslide.
- June – A rock fall composed mostly of a 20 foot boulder fell onto Mission Creek Road, near Cashmere in Chelan County on June 12.
- November – Cayuse Pass closed on November 13 due to a large rockslide, inside the Mt. Rainier National Park boundary. The slide was cleared within the day, but continued instability on the slope continued the closure until November 20.
- December– The storm event of December 1–3, 2007, was a truly historic event, where snow, strong winds, and heavy rainfall battered western Washington, triggering thousands of landslides and causing major flooding on numerous rivers.

Hazard Profile – Landslide

The storm came in three parts, bringing winds and heavy snow on December 1. Warm temperatures and heavy rain followed on December 2-3, rapidly melting snow. Hurricane force winds blew into the area on December 3rd, hugging along the coastline with sustained winds of 80 miles per hour with gusts up to 145 miles per hour. It created a massive blowdown zone of timber, 600 to 800 million board feet, along the coastline, but was relatively sheltered from the intense rain and rapid snowmelt.

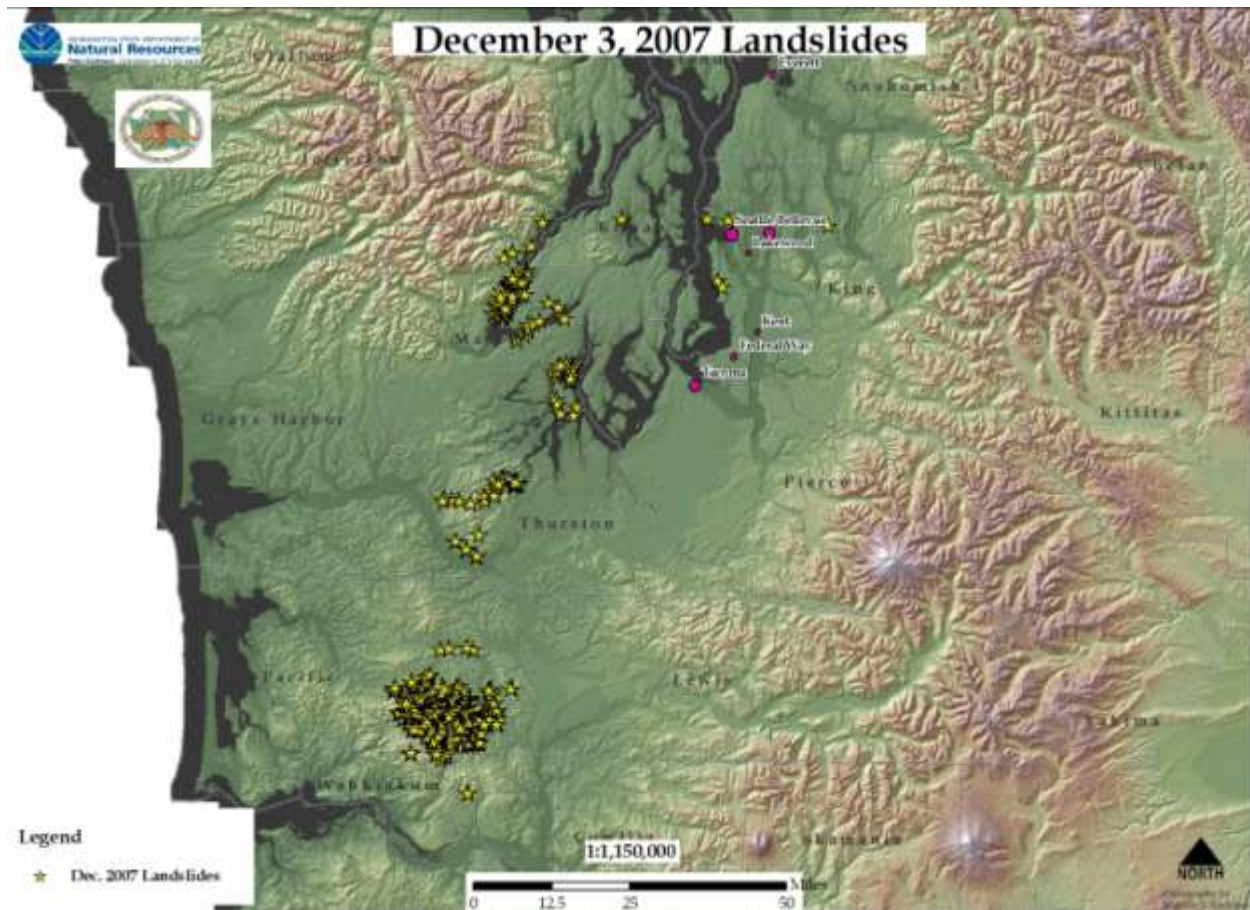


Figure 3. Landslide initiation points from the December 3, 2007 Storm

Landslides blocked or damaged roads, isolating communities in the height of the storm and delaying emergency response. At least one person died as a consequence of the storm. The precipitation was mostly concentrated on the western side of Puget Sound and created a band of landslides from Mason County to Jefferson County. Just west of Pe Ell (Lewis County), a massive debris avalanche along with numerous smaller landslides blocked State Route 6, from Pe Ell to Raymond, isolating 21 households without electricity and water. In addition, State Route 8, just west of the SR 101 interchange in the vicinity of MP 18, State Route 12 in the vicinity of MP 27 between Porter and Malone, and SR 508 near Onalaska were blocked by landslides.

Hazard Profile – Landslide

In the Chehalis headwaters area, the hardest hit area from the storm, nearly 20 inches of rain was recorded within a 48-hour period, most of that falling within the first 24 hours. Intense flooding followed the heavy rain, primarily along the Chehalis River. Woody debris and sediment, including material from more than 1,000 landslides in the Chehalis headwaters basin, partially clogged the flood waters for a time. Debris clogged channels at bridges, creating temporary dams and causing widespread deposition of logs and debris, especially across the Boistfort valley. The flood waters reached Chehalis and Centralia on December 3, inundating Interstate 5 (I-5) with as much as 10 feet of water and flooding numerous homes. The flood waters persisted and closed I-5 until December 6, when flood waters finally receded enough to reopen the interstate.

Numerous landslides occurred in Capital Forest, one destroying the Ranch House BBQ business on Highway 8. Landslides also occurred at the interchange of Highway 101 and Highway 8, temporarily closing both. Landslides blocked Highway 101 north of Skokomish River. Numerous debris flows, debris avalanches, and hyperconcentrated flows blocked the freeway, isolating communities along Hood Canal. Holiday Beach was hardest hit, with at least eight houses affected by a hyperconcentrated flow through the middle of the community. On the eastern shores of Hood Canal, numerous debris flows closed the North Shore Road and destroyed one house. Only eight landslides were recorded in the Seattle-Everett area, most of them localized and caused minor impacts to roads.

In 2008

- January – In Skamania County, along the scarp of the Bonneville Landslide in Greenleaf Basin, a massive landslide moved during the winter. The landslide was about 30 acres in size. Higher winter rainfall in December probably contributed to the failure.
- May – A Landslide near Leavenworth closed Icicle Creek Road, about 15 miles west of Leavenworth. The landslides occurred on May 18 and were the result of a snow avalanche triggering two debris flows. The landslides diverted water from Icicle Creek onto the roadway and blocked three Forest Service campgrounds in the Icicle Valley.
- July – A large thunderstorm in King County on July 4 resulted in a landslide near 166th Avenue Southeast in Bellevue, at a subdivision under construction. The landslide was removed and the slope repaired the same day.
- August – Thunderstorms over the Methow Valley in Okanogan County on August 19 caused flash flooding and landslides in the area. At least two landslides (hyperconcentrated flows?) partially blocked Highway 20, one near the junction of Highway 153, the other near Loup Loup Pass. Another landslide was reported to have covered the Methow Valley Irrigation District ditch, diverting the water onto the road.

Hazard Profile – Landslide

- November – A rockslide on November 7 has closed Chuckanut Drive (Hwy 11). Several other rockslides continued to move between MP 9.7 and 13.3. The closure continued for four weeks as WSDOT conducted emergency rockfall stabilization.

On November 12, a storm caused flooding and localized landslides. In King County, a debris flow closed SR 410 near Greenwater River, east of Enumclaw. The landslide was reported to be 50 feet long by up to 20 feet high. On State Route 169, a landslide impacted the south abutment of the Green River Bridge, causing a closure of the highway and bridge for 8 months to complete emergency repairs to the bridge abutment and highway. In Grays Harbor, a small landslide occurred at the Aberdeen Bluffs, diverting stormwater onto Highway 12. A landslide partially blocked the northbound lane of State Route 107 at Melbourne Road, just south of Montesano.

- December – A landslide and rockslide blocked Highway 112, near Neah Bay on Dec. 22. The landslide isolated the town on the Makah Indian Reservation.

In 2009

- January – The January 7-8th Storm was a typical Pineapple Express storm, bringing warm rains that originated from around Kauai (Hawaiian Islands) and rapidly melting snow in a rain-on-snow event. The rainfall followed lowland snow in the Puget Sound region from December 2008 into January 2009, resulted in high amounts of flooding and saturation of soils. Washington Geological Survey reported through field and aerial surveys that the storm caused over 1,500 landslides (above 5,000 sq.ft. in size). The storm also resulted in widespread flooding in Western and parts of Eastern Washington. The flooding resulting in the largest evacuation in state history, forcing more than 30,000 people living in the Puyallup River area to flee. Landslides were reported from Cowlitz County to Whatcom County and from the coast and into Kittitas and Yakima counties. The most intense rainfall occurred along the Cascade Mountains, where the majority of landslides also occurred. The hardest hit areas were eastern Lewis, Skagit, and Whatcom Counties.

Hazard Profile – Landslide

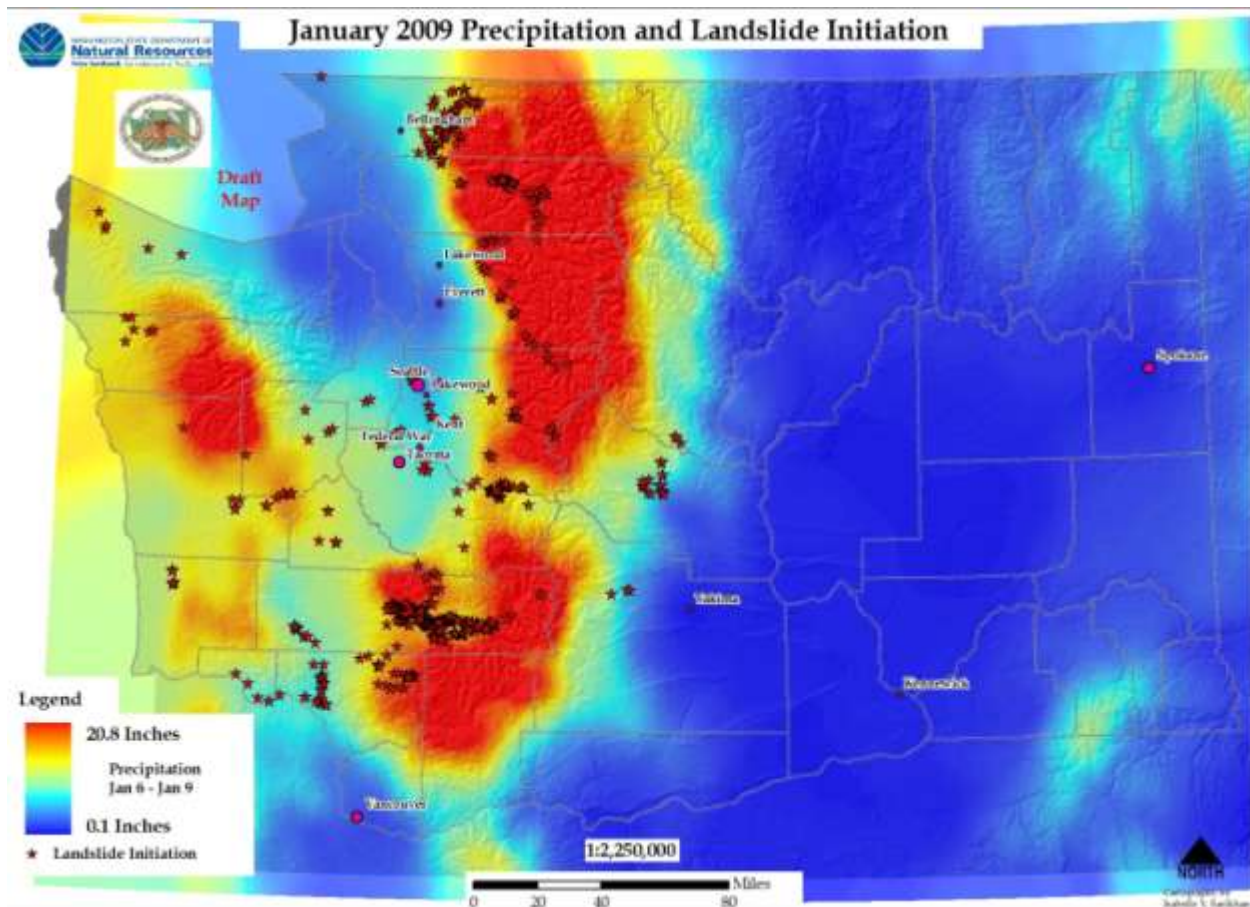


Figure 4. January 7-8, 2009 storm and landslide initiation.

In Lewis County, hundreds of debris flows between Morton and Randle flowed into the valley, destroying houses and blocking Highway 12. The debris flows were very long reaching, often transforming into hyperconcentrated flows on the valley floor and moving for miles downstream. Many of the hyperconcentrated flows were channelized into roadways by plowed snow from earlier snow storm events. Over 500 landslides were recorded in Eastern Lewis County with an unknown number of houses damaged. No deaths were reported.

In Skagit and Whatcom Counties, debris flows blocked roads and damaged or destroyed houses. In Skagit County, the town of Concrete had several debris flows damage houses, forcing an evacuation away from the surrounding unstable slopes. In Whatcom County, debris flows were most concentrated in Chuckanut Formation. Debris flows generally were isolated into channels that flowed onto alluvial plains. Approximately 300 to 500 landslides occurred in Skagit and Whatcom Counties.

In Kittitas County, a large debris avalanche formed on the Hyak Ski area on Snoqualmie Pass. The landslide destroyed numerous buildings and ski infrastructure. Numerous landslides around Blewett Pass blocked Highway 97, resulting in its closure. In the Pierce, King, and Snohomish Counties, landslides occurred mostly in the Cascade foothills. Highway 410 near Greenwater was closed due to numerous debris flows across the highway, isolating the town of

Hazard Profile – Landslide

Greenwater. In Clark County, landslides dotted around the I-5 corridor and numerous landslides occurred in the Kelso and Longview area. Numerous landslides were also recorded on or near Highway 504 (Spirit Lake Highway). A smaller number of landslides were many of the other counties within Western Washington.

Highway infrastructure was most impacted along SR 112 in the vicinity of MP 37 where 500 feet of roadway dropped up to 8 feet, closing the highway indefinitely; the southern portion of US Highway 101 in the vicinity of MP 43 and 60.6; the Cowlitz River valley where several landslides and one major rockfall closed the highway for two days between Mossy Rock and Randal; the Tilton River drainage where the SR 508 bridge footing was scoured at Morton and a landslide subsided up to one foot on the west side of Bear Canyon; the Lewis River drainage where SR 503 was temporary closed by landslides in the vicinity of MP 30.3 and 37.7; the Snoqualmie River drainage where a landslide occurred on Interstate 90 in the vicinity of MP 36; the Cedar River drainage where the Cedar River bridge approach wall failed on SR 169 from river scour and a retaining wall near the Issaquah-Hobart interchange on SR 18 was undermined; near McCleary a landslide impacted the roadway in the vicinity of MP 8.5 on SR 108; and another landslide occurred adjacent to a home on SR 122 in the vicinity of MP 6.2.

Perhaps the most damaging part of the January 2009 storm was the potential reactivation of movement of the landslide underneath Howard Hansen Dam, which might have caused a subterranean leak on the dam in King County. The leak was detected shortly after the January storm. The dam prevents wide scale flooding in the Kent Valley, but at a weakened strength, the dam may be forced to release flood waters.

On January 16, a landslide on the Spokane River arm of Lake Roosevelt resulted in an inland tsunami, creating a wave about 30 feet high. The tsunami destroyed numerous docks and did some damage to houses along the waterfront.

- March – A rockslide on Mar. 23 blocked the Entiat River Road in Chelan County. The landslide was about 11 miles northwest of Entiat.
- April – A hyperconcentrated flow moved through Glendale on south Whidbey Island on April 3rd, the result of a dam-burst flood. A 100 to 150 foot section of the road on Glendale Creek gave way after a beaver dam collapsed, resulting in the hyperconcentrated flow. In Chelan County, an irrigation pipe leak resulting in a landslide on April 21. The landslide occurred on the 1000 block of Vista Place and resulted in damage to a fence and tree. Two landslides on April 25 moved across Brender Canyon Road near Cashmere, Chelan County. One of the landslides was reported to be about 20 feet wide by about 4 feet deep.
- May – A rockslide on Interstate 90 temporarily closed eastbound lanes for five hours on May 12. The slide was mostly the result of one boulder, with a minor amount of other debris.

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- July – A debris flow on July 29 closed the North Cascades Highway near Rainy Pass. The landslide was triggered following several days of thunderstorms. The landslide was reported to be about 900 feet long by about 10 feet deep along the Highway.
- August – An abutment along a railroad track in Stevens County gave way on August 6, resulting in a small landslide. A train was derailed as a result of the damaged railroad tracks. On August 25, a landslide on the Spokane River arm of Lake Roosevelt resulting in an inland tsunami. The tsunami damaged the Porcupine Bay Campground and injured two children.
- October – A massive landslide started to move on October 10 west of Naches near the town of Nile. On October 11, the landslide catastrophically failed, diverting the Naches River covering Highway 410, and damaging 6 houses by ground deformation and over 20 by flooding.



Figure 5. An oblique photo of the Nile Landslide, photo by Jack Powell, DNR

Following the landslide movement Yakima County purchased 60 acres of land that included several homes at a cost of \$1.78 million to realign the Naches River channel and a new road. WSDOT constructed a temporary route for Highway 410 on the other side of the valley. In response to the danger of the landslide, WSDOT, DNR, and the University of Washington monitored the landslide for

Hazard Profile – Landslide

movement. A radar system was employed to monitor landslide movement, monuments were set up on the landslide and portable seismometers were utilized to detect any precursor to further movement of the landslide.

- November – Storms from November 15 to 24 triggered a handful of landslides. On November 16th, a landslide occurred on Hwy 101, near Ayock, another at 29th Court NW near Shawnee Drive, which damaged a garage, and a deep-seated earthflow in Clallam County on a forest service road. Continued rains triggered a landslide on November 17th along the tracks of Seattle, 4 miles north of Carkeek Park.

Jurisdictions Vulnerable to Landslides

Analysis of risk to local jurisdictions is a difficult process. Currently, there are no comprehensive statewide landslide hazard maps. However, models exist to aid in detecting potential areas more susceptible to landslides in some locations. All counties in Washington State have some landslide hazard and risk. In Washington State, landslide risk is higher in western Washington due to the higher amount of precipitation. Water and gravity are the main drivers of landslides. In Eastern Washington, the landslide risk is high during storm events (especially spring and summer thunderstorms) and in places where irrigation is near bluffs or near or on deep-seated landslides. Earthquakes have the potential to cause landslides in Eastern and Western Washington.

Based on descriptions of events and damages described above, as well as information from landslide experts from the Washington Department of Natural Resources and the U.S. Geologic Survey consulted for this profile, the following jurisdictions have the greatest vulnerability to landslides.

Asotin	Chelan	Clallam	Clark	Columbia
Cowlitz	Ferry	Garfield	Grays Harbor	Island
Jefferson	King	Kitsap	Kittitas	Klickitat
Lewis	Lincoln	Mason	Okanogan	Pacific
Pierce	San Juan	Skagit	Skamania	Snohomish
Stevens	Thurston	Walla Walla	Whatcom	Yakima

Parts of these jurisdictions have one or more of the following areas that are prone to landslides:

- Shorelines of Pacific Coast, Puget Sound and Hood Canal.
- Shoreline of Lake Roosevelt and the Columbia River Gorge.
- Slopes of the Blue, Cascade, and Olympic mountain ranges.
- Corridors of Interstate 5 and U.S. Highway 101. Corridors.

Hazard Profile – Landslide



Washington Geologic Survey Landslide Database

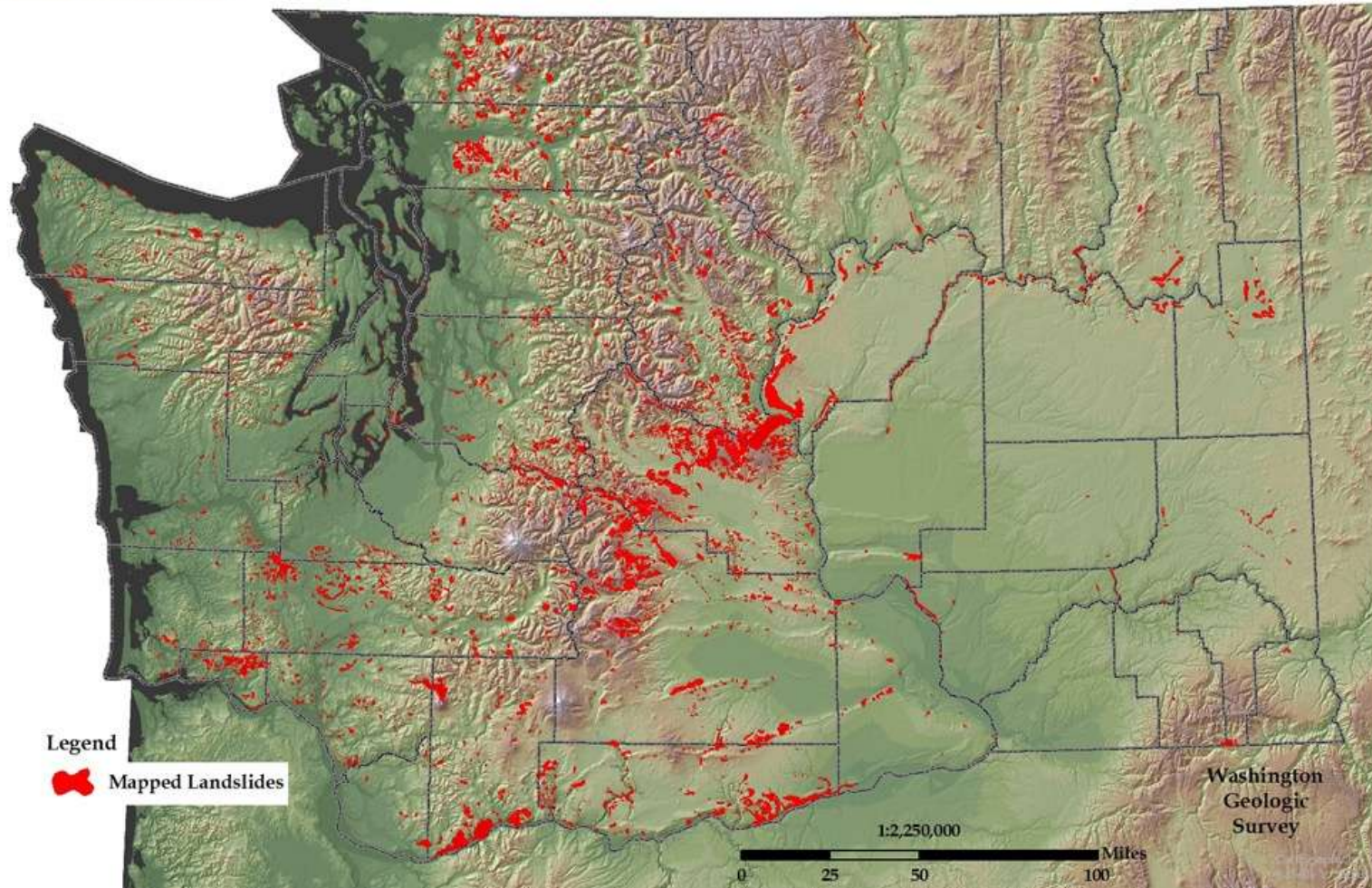


Figure 6. The Washington Geologic Survey's statewide landslide database, representing both 100k and 24k landslides. This database is only a partial representation of landslides in Washington State and does not represent all landslides within Washington State. (2009)

Hazard Profile – Landslide

Counties and Areas Vulnerable to Landslides

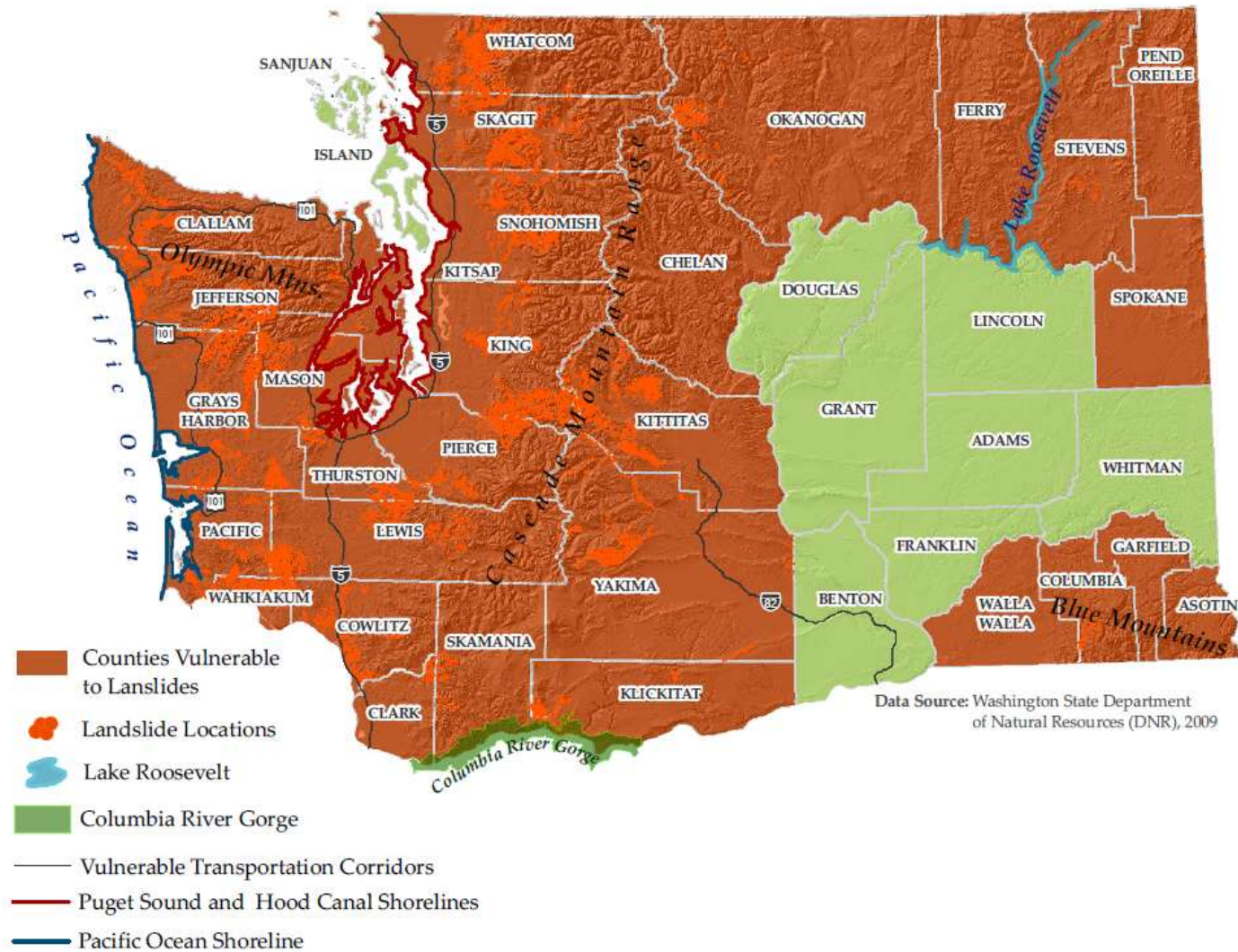


Figure 7. Counties Vulnerable to Landslide Hazards. Counties within in Washington State that contain known landslides are considered at-risk to future landslide activity.

Hazard Profile – Landslide



Public Facilities Potentially at Risk to Landslide Hazards

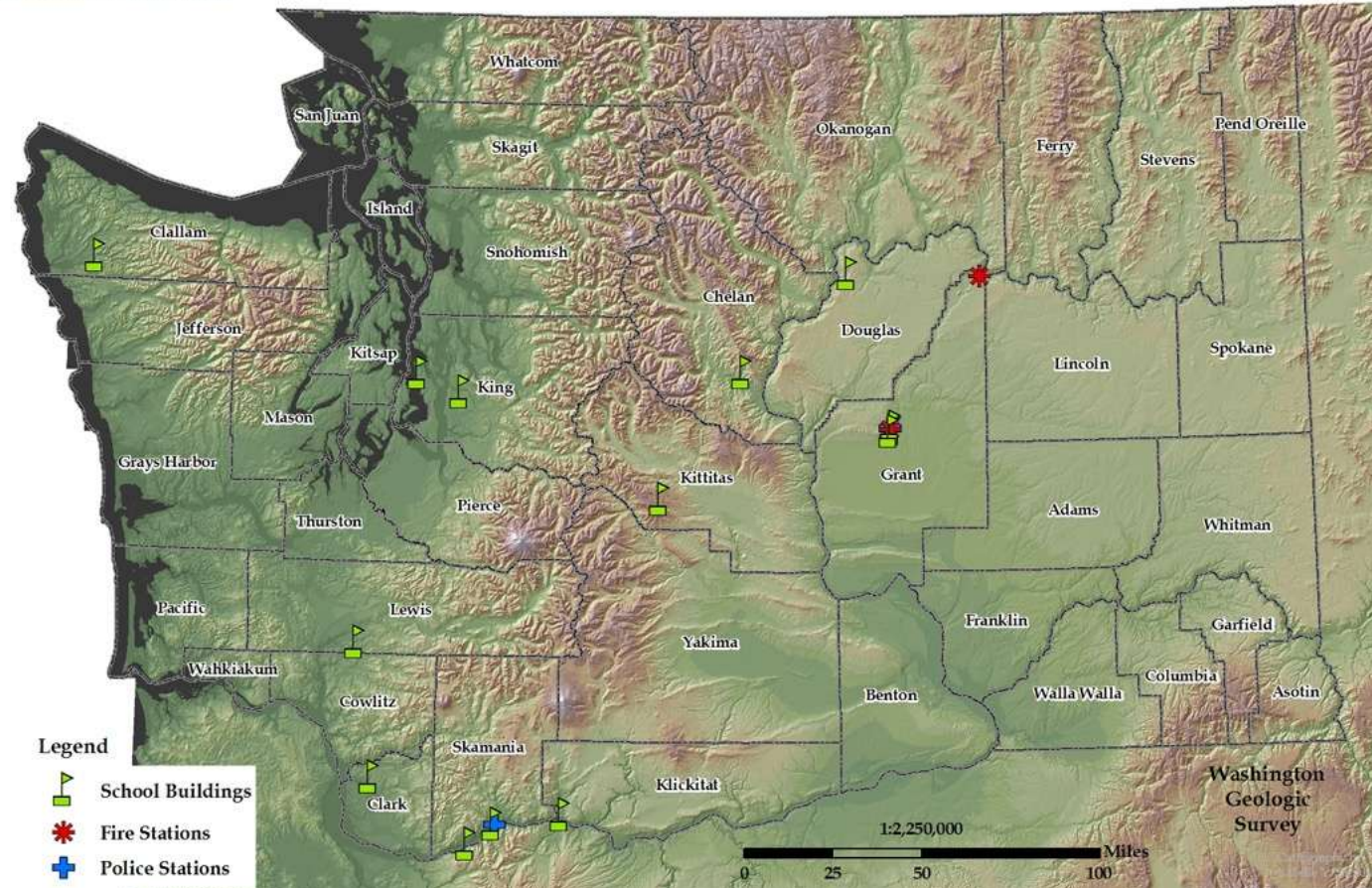


Figure 8. County owned public facilities in or within 100 feet of a landslide within the Washington Geologic Survey's landslide database. These facilities are potentially at risk for future landslide activity

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Since no statewide landslide susceptibility map exists, a detailed analysis of public facilities is difficult. However, a simple analysis of public facilities on or nearby landslides indicates 23 facilities potentially at risk of future landslide activity. The risk could include reactivation of a deep-seated landslide or in areas susceptible to shallow landslides, such as debris flows. This simple analysis does not exclude features not shown on the map from landslide risk.

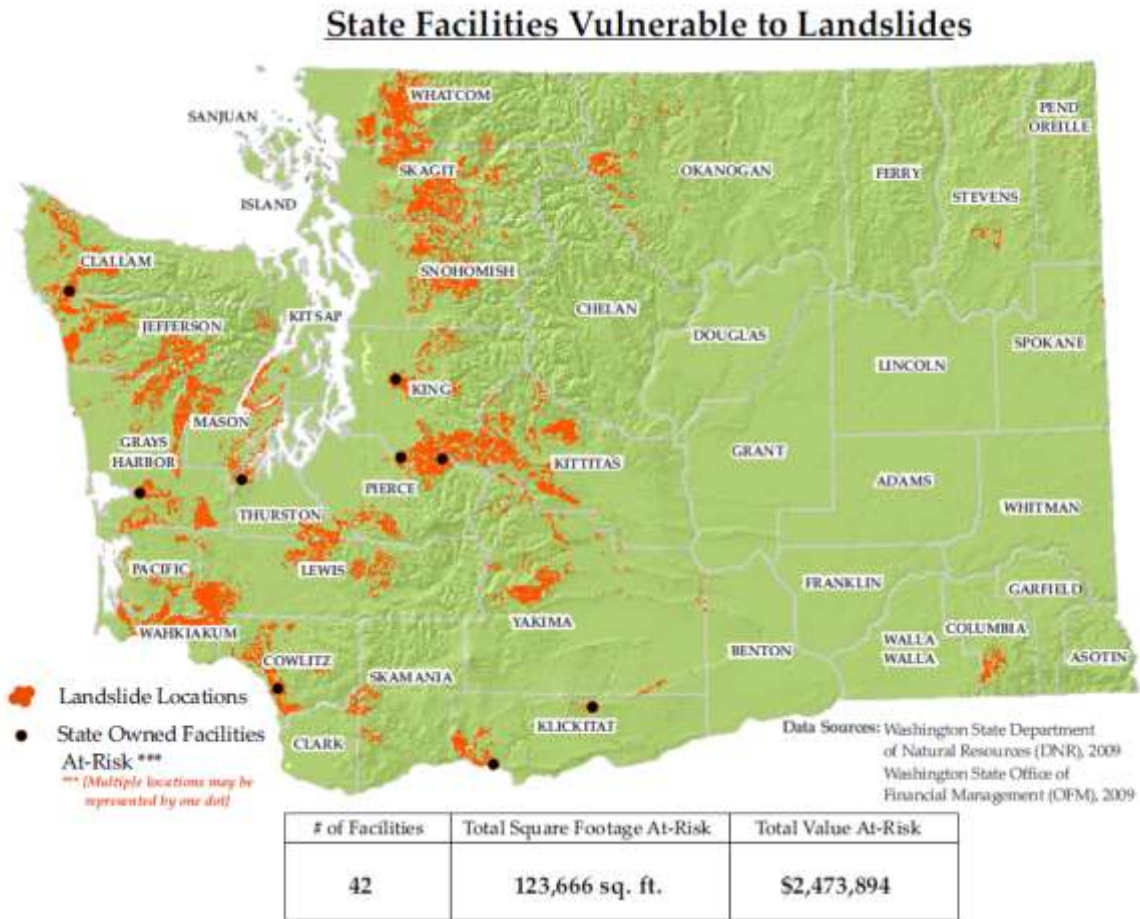


Figure 9. State Owned Facilities within 500 feet a location of a known landslide according to the Washington Geologic Survey's 2009 Landslide Database at 24K.

Utilizing the Washington State Office of Financial Management's 2009 dataset of state leased and owned facilities, an analysis was performed to determine which, if any, state facilities may be at risk to a future landslide. For the state owned facilities in this dataset, 42 were determined to be within 500 feet of a landslide and may therefore be at risk to future landslide activity. These state owned facilities represent over 123,000 square feet of office space with a total value of over \$2.4 million dollars (building stock only, no content). An identical analysis of state leased facilities was performed, but no state leased facilities were determined to be within the specified distance of any known landslide location contained in the landslide database.

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LOSS ESTIMATION

State Agency Structures At Risk



Landslide:

	# of Facilities	Total Original Cost	Avg. Original Cost	Total Square Feet	Average Sq. Ft.
Owned:	42	\$2,473,894	\$58,902	123,666	2,944
	# of Essential Facilities	Total Original Cost	Avg. Original Cost	Total Square Feet	Average Sq. Ft.
	12	\$754,830	\$62,902	82,727	6,893
	# of Facilities	Total Monthly Rent	Avg. Monthly Rent	Total Square Feet	Average Sq. Ft.
Leased:	0				
	# of Essential Facilities	Total Monthly Rent	Avg. Monthly Rent	Total Square Feet	Average Sq. Ft.
	0				

State owned structures within hazard zone:

Nine state highways considered emphasis corridors because of their importance to movement of people and freight are potentially at risk to landslide and ground failure:

1. Interstate 5
2. Interstate 82
3. Interstate 90
4. U.S. Highway 2
5. U.S. Highway 12
6. U.S. Highway 97
7. U.S. Highway 101
8. U.S. Highway 395
9. State Route 20

Additionally, ferry landings in Anacortes, Bainbridge Island, Bremerton, Clinton, Fauntleroy, Keystone, Mukilteo, Port Townsend, the San Juan Islands, Seattle, Southworth, Tacoma, and Vashon Island are potentially at risk because of their construction on poor soils in shoreline areas.

State critical facilities at risk within hazard zone:

Nine state highways considered emphasis corridors because of their importance to movement of people and freight are potentially at risk to landslide and ground failure:

1. Interstate 5
2. Interstate 82
3. Interstate 90
4. U.S. Highway 2
5. U.S. Highway 12
6. U.S. Highway 97
7. U.S. Highway 101
8. U.S. Highway 395
9. State Route 20

Additionally, ferry landings in Anacortes, Bainbridge Island, Bremerton, Clinton, Fauntleroy, Keystone, Mukilteo, Port Townsend, the San Juan Islands, Seattle, Southworth, Tacoma, and Vashon Island are potentially at risk because of their construction on poor soils in shoreline areas.

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Resources

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